Fishery Manuscript No. 93-1

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[1] This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-8, Job Number R-3-4(c).

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ABSTRACT

Populations of northern pike *Esox lucius* in four Interior Alaskan lakes (George, Volkmar, T, and Harding) were studied from 1985 to 1993. Abundance, recruitment, mortality, and age composition were measured for fish over 499 millimeters fork length using mark-recapture techniques. Both theoretical and empirical models of logistic surplus production, along with the Ricker method, were used to analyze the stock-recruitment relationship and estimate sustainable yield in terms of subsequent recruitment at maturity. Current estimates of abundance exceeded the optimum expected to maximize surplus production (N_{MSY}) of northern pike in George, were close to optimum in Volkmar and T, and were half the optimum value in Harding Lake. Estimates of population intrinsic rate of increase (r) were similar (mean = 0.45) in all lakes except Harding, which was lower. Densities at N_{MSY} (fish/ha), projected with the surplus production models, ranged from 1.6 in T Lake to 6.7 in George Lake (mean = 4.2). The potential sustainable yield ranged from 0.4 in Harding and T lakes, to 1.4 northern pike/ha in George Lake. Preliminary analysis using the Ricker stock-recruit model described a value for N_{MSY} one-third of that estimated by the empirical LSP for the population in Volkmar Lake, with closer agreement between predicted and estimated recruitment observed to date.

KEY WORDS: Northern pike, *Esox lucius*, Volkmar Lake, George Lake, T Lake, Harding Lake, mark-recapture, abundance, maximum sustainable yield, surplus production.

INTRODUCTION

Background

Northern pike *Esox lucius* are popular with sport anglers in Alaska. An estimated 100,642 northern pike were caught statewide during 1992, of which 18,616 (18%) were harvested (kept) according to Mills (1993). Excluding anadromous and saltwater species, northern pike ranked third in preference (following rainbow trout *Oncorhynchus mykiss* and Arctic grayling *Thymallus arcticus*) of freshwater fish both caught and harvested statewide during 1992. In the Arctic-Yukon-Kuskokwim region (AYK) during 1992, where the highest percentage (61%; 11,302) of the statewide harvest of northern pike occurred, northern pike ranked fourth among all species harvested in recreational fisheries, and second for those non-anadromous species considered indigenous to the region. These harvests of northern pike in the AYK region have averaged about 15,103 fish between 1977 and 1992, with a harvest range from 11,302 to 20,771.

Within AYK, harvest of northern pike from waters of the Tanana River drainage comprised 54% (6,148 fish) of the regional total for the species during 1992. East Twin, George, Harding, and Volkmar lakes, in that order, were the sites of the most popular fisheries for northern pike in the Tanana River drainage during 1992, accounting for 27% (1,647 fish) of the total harvest.

Cursory stock assessment and creel surveys of northern pike in the Tanana River drainage were conducted from 1968 to 1984 (Alt 1969; Cheney 1971-1972; Hallberg 1983; Peckham 1972-1985). Research initiated at Volkmar Lake in 1985 (Peckham 1986) provided the first estimate of northern pike abundance. Research conducted from 1986 through 1993 has provided additional estimates of abundance, along with information on catch-per-unit of sampling effort (CPUE), catchability, sampling methods, life history, and age, sex, and size composition of northern pike in George, Volkmar, T, and Harding lakes (Peckham and Bernard 1987; Clark et al. 1988; Clark 1988; Clark and Gregory 1988; Timmons and Pearse 1989; Burkholder 1991; Pearse 1990, 1991; Hallberg and Bingham 1992; Pearse and Hansen 1992; Pearse and Burkholder 1993; Pearse and Clark 1992; Roach 1992; Skaugstad and Burkholder 1992).

This report documents the application of two models to estimate maximum sustainable yield (MSY) of northern pike populations in George, Volkmar, T, and Harding lakes.

Study Area Descriptions

George Lake:

George Lake (63°47'N, 144°31'W) is a semi-remote 1,823 ha lake located approximately 45 km southeast of the town of Delta Junction (Figure 1). The lake is accessible from late-May to early-October (the open water season) by either float-equipped aircraft, or boat via the Tanana River and then the outlet, George Creek. Although George Creek is navigable, it is shallow. To access the lake a conventional boat powered with a jet unit, an outboard

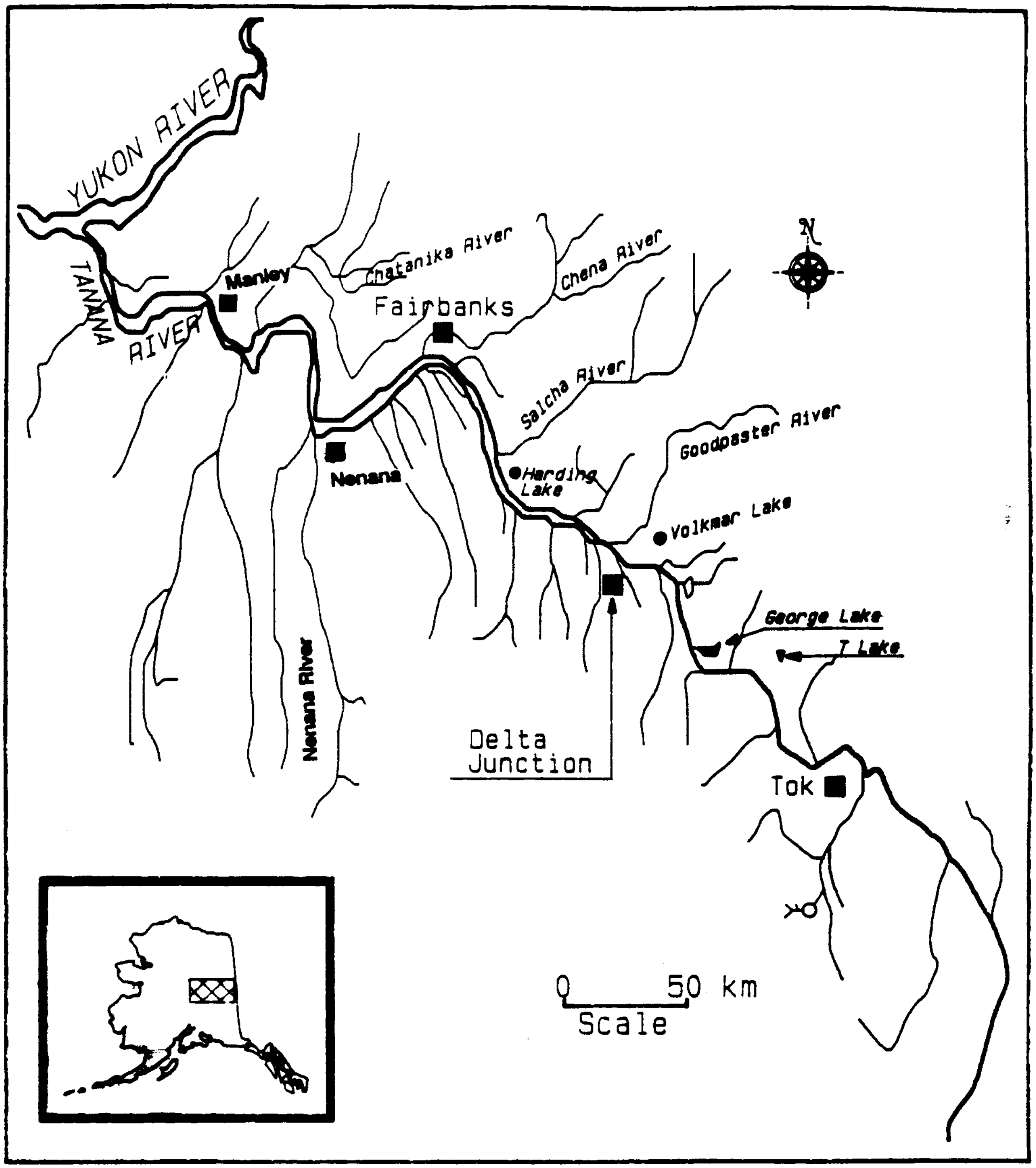

Figure 1. Tanana River study areas.

equipped with a lift device, or an airboat is required. Snow machines and ski-equipped aircraft provide access during winter. George Lake lies at an elevation of 389 m and has a maximum depth of 11 m. The lake has one major and six minor inlets. Spawning of northern pike in George Lake generally coincides with the beginning of the ice-free season and continues into early-June. George Lake contains northern pike, Arctic grayling, burbot *Lota lota*, humpback whitefish *Coregonus pidschian*, least cisco *Coregonus sardinella*, round whitefish *Prosopium cylindraceum*, longnose suckers *Catostomus catostomus*, and slimy sculpin *Cottus cognatus*.

From 1981 through 1992, the estimated annual fishing effort averaged 1,157 angler-days (ad) (range 557 to 1,957; Mills 1993; Appendix A). The estimated average fishing pressure is 0.6 angler-day/hectare (ad/ha) and the estimated harvest averaged 1,647 northern pike, (range 529 to 3,076), with an average success of 1.4 northern pike harvested per angler-day. In 1992, 18% of the catch was kept. The average annual harvest per hectare is 0.3 northern pike. Recreational fishing occurs year-round however, harvest estimates by season are not available.

Northern pike investigations in George Lake began in the early 1970's with limited sampling to estimate size and age composition of the northern pike population (Peckham 1972-1986). The current research program on northern pike began in 1986, and abundance and length and age composition of the population have been estimated annually from 1987 through 1992 (Clark et al. 1988; Timmons and Pearse 1989; Pearse 1990, 1991; Pearse and Burkholder 1993).

Volkmar Lake:

Volkmar Lake (64°07'N, 145°11'W) is a remote 273 ha lake located approximately 25 km northeast of the town of Delta Junction (Figure 1). The lake is accessible during the open water season by float-equipped aircraft. Snow machines and ski-equipped aircraft provide access during the winter. Volkmar Lake lies at an elevation of 326 m and has a maximum depth of 12.8 m. The lake has two small inlets and an ill-defined outlet that is likely closed to the passage of fish. Spawning generally begins in mid-May and continues for up to two weeks. Other fish species present include humpback whitefish, least cisco, and slimy sculpin.

The popularity of Volkmar Lake as a recreational area continues to grow due to land disposals around the lake by the State, improved winter access from new snow machine trails and roads in the Delta Junction Agricultural Project, and increased summer and winter use by cabin owners around the lake and on the nearby Goodpaster River. For the period 1981 through 1992, estimated annual fishing effort averaged 494 ad (range 129 to 1,052; Mills 1993; Appendix A) and an estimated average fishing pressure of 1.8 ad/ha. The estimated harvest for northern pike averaged 415, ranging from 84 (1990) to a high of 777 (1982), with an average harvest of 0.8 northern pike per angler-day. In 1992, 18% of the catch was harvested. The average annual harvest per hectare is 1.5 northern pike.

The research program of northern pike in Volkmar Lake began in 1985. Annual estimates of abundance, size, and age composition of its population have been obtained through the summer of 1993 (Clark and Gregory, 1988; Timmons and Pearse, 1989; Pearse 1990, 1991; Pearse and Clark 1992; and Pearse and Burkholder, 1993).

T Lake:

T Lake (63°48'N, 143°53'W) is a remote fly-in lake located approximately 18 km north of the village of Dot Lake along the Alaska Highway (Figure 1). The 158 ha lake lies at an elevation of 434 m and has a maximum depth of 17 m. The lake has two small inlets and an intermittent outlet. Spawning occurs during a time frame similar to Volkmar Lake. Other fish species in the lake include burbot, humpback whitefish, and least cisco. Fishing pressure and rates of exploitation are believed to be low compared with other populations (Appendix A). Stock assessment studies have been conducted annually since 1986 (Peckham and Bernard 1987; Clark 1988; Timmons and Pearse 1989; Pearse 1990, 1991; Pearse and Burkholder 1993).

Harding Lake:

Harding Lake (64°25'N, 146°50'W) is located 54 km (69 km by road) southeast of Fairbanks (Figure 1). The lake can be reached by three roads that exit the Richardson Highway. The surface elevation is 217 m, surface area is 1,000 ha, and maximum depth is 43 m. In addition to runoff, the lake is fed by springs, permafrost seeps, and two inlets; there is no outlet. The littoral zone comprises 33% of the surface area. Indigenous species include northern pike, burbot, least cisco, lake chub *Couesius plumbeus*, and slimy sculpin. Introduced species include lake trout *Salvelinus namaycush*, coho salmon *Oncorhynchus kisutch*, sockeye salmon *Oncorhynchus nerka*, rainbow trout, inconnu *Stenodus leucichthys*, Arctic char *Salvelinus alpinus*, and Arctic grayling. From 1983 to 1992, the estimated annual fishing effort ranged from 708 to 5,155 ad, and averaged 3,276 (Mills 1993; Appendix A). This equates to an estimated average fishing pressure of 3.3 ad/ha. The estimated harvest averaged 1,068 northern pike, ranging from 178 (1983) to 2,092 (1988) fish, with an average success of 0.3 northern pike per angler-day kept. In 1992, 10% of the catch was harvested. The average annual harvest per hectare is 0.3 northern pike. The first major stock assessment of northern pike in Harding Lake occurred in 1990 (Burkholder 1991) with abundance and length and age compositions estimated annually through the summer of 1993 (Skaugstad and Burkholder 1992).

Study Goals and Objectives

The long-term goal of the northern pike research program is to accurately and precisely describe the stock status of selected northern pike populations on an annual basis, and to use the data to estimate maximum sustainable yield (MSY).

The specific objective for Federal Aid Project F-10-8, Job R-3-4 (c) was to estimate sustainable yield for selected northern pike populations in the AYK Region.

METHODS

Sampling Techniques

Northern pike in interior Alaskan lakes are best sampled during and immediately after the spawning period when they concentrate in near-shore waters to spawn and feed, and when low water temperatures minimize handling induced injuries (Peckham and Bernard 1987; Clark 1988; Pearse and Clark 1992). Fish were captured in George and Volkmar lakes with a bag seine set in water less than 2 m deep in known spawning and feeding areas, usually within 100 m of the shore. Gill nets were used in T Lake to capture northern pike because of previous limited success with seines (Pearse 1990). Both gill nets and backpack electro-fishing units were used to capture northern pike in Harding Lake (Skaugstad and Burkholder 1992). Each fish captured was measured to the nearest mm fork length (FL), and their sex was recorded, if determined, by the extrusion of gametes. Scales were removed from each captured fish (except in 1992). See Pearse and Hansen (1992) for details regarding procedures used to estimate ages of northern pike from scales. All untagged, apparently healthy northern pike in the samples were released after being marked with a Floy FD-68B internal anchor tag and with a variety of fin clips and punches. See Pearse and Hansen (*In prep*) for further details relative to specific sampling methods, sample sizes and timing of the annual events for the respective populations of northern pike.

Population Abundance, Recruitment, and Survival

Survival rates, recruitment, and abundance of northern pike were estimated in a single, multiple-year mark-recapture experiment at George Lake and with annual, single-year, mark-recapture experiments at Volkmar, T, and Harding lakes. The methodology and results of these studies are summarized by Skaugstad and Burkholder 1992, and Pearse and Hansen *In prep*.

In George Lake there are six estimates of abundance and length composition (1987-1992), and five estimates of age composition (1987-1991) for the population of northern pike. The Petersen abundance estimator (Ricker 1975) was used to estimate population size for northern pike ≥300 mm FL. However, there were several years where marked fish did not mix completely with unmarked fish within a given sampling season (Pearse 1991). If fish are marked and recaptured in the same area, and there has not been sufficient time for the marked fish to mix with the unmarked fish, the Petersen abundance estimator will underestimate the population. Because marked and unmarked northern pike would be expected to sufficiently mix between annual sampling events, a multi-year Jolly-Seber model (Seber 1982) was used to re-estimate abundance of fully recruited northern pike in George Lake. The software package JOLLY (Pollock et al. 1990) was used to perform the calculations.

The Petersen population estimator was used to calculate within and between season abundance of northern pike ≥300 mm FL for Volkmar, T, and Harding lakes. Estimated tag loss between annual sampling events ranged from 5 to 25% in Volkmar Lake, and from 3 to 28% in T Lake, and was negligible in Harding Lake. Because of this high rate of tag loss, the Jolly-Seber model was not used.

Northern pike are considered fully recruited to the sampling population at lengths ≥500 mm FL or age 5, in George, Volkmar, and Harding lakes. In T Lake, the northern pike grow more slowly and are not fully recruited to the sampling gear until age 6 (Pearse 1991). Age at initial full recruitment (sexes combined) was assessed based upon the highest average abundance of the youngest cohort in each waterbody over the time periods studied. The length at full recruitment (≥ 500 mm FL) was the mean length of all fish in the recruited cohort, regardless of age. Males were generally shorter than females at a given age. Recruitment (R) has been estimated annually (Pearse and Hansen *In prep*) as the abundance of age 5 northern pike (age 6 northern pike in T Lake) and was calculated as the proportion of the sample of age 5 (or age 6 for T Lake) northern pike multiplied by the estimated abundance of northern pike (Pearse and Hansen *In Prep*).

In Volkmar, T and Harding lakes where the Petersen abundance estimator was applied, age composition was used to estimate survival and mortality rates. Survival rate was estimated as:

$$\hat{S}_{t,t+1} = \frac{\hat{N}_{t+1} - \hat{R}_{t+1}}{\hat{N}_t}. \qquad (1)$$

where:

$\hat{S}_{t,t+1}$ = estimated survival rate from year *t* to *t+1*;
$\hat{N}_{t+1}$ = the estimated abundance of fully recruited fish in year *t+1*;
$\hat{R}_{t+1}$ = the estimated recruitment year *t+1*; and,
$\hat{N}_t$ = estimated abundance of fully recruited fish in year *t*;

The variance for $\hat{S}_{t,t+1}$ was estimated as a sum of the variances of a product from Goodman (1960):

$$\hat{V}[\hat{S}_{t,t+1}] = V(a)b^2 + a^2V(b) - V(a)V(b) \qquad (2)$$

where:

$$\begin{aligned} a &= \hat{N}_{t+1} - \hat{R}_{t+1} \\ &= \hat{N}_{t+1} - \hat{p}_{a_{t+1}}\hat{N}_{t+1} \\ &= \hat{N}_{t+1}(1 - \hat{p}_{a_{t+1}}) \end{aligned}$$

$$V(a) = V\left(\hat{N}_{t+1}\right)\hat{p}^2_{a_{t+1}} + V\left(\hat{p}_{a_{t+1}}\right)\hat{N}^2_{t+1} - V\left(\hat{p}_{a_{t+1}}\right)V\left(\hat{N}_{t+1}\right)$$

$$b = \left[\frac{1}{\hat{N}_t}\right]$$

$\hat{V}(b)$ = estimated by the delta method as:

$$\frac{1}{\hat{N}_t^4} V(\hat{N}_t)$$

The instantaneous rate of mortality was calculated as:

$$\hat{Z}_t = -\ln(\hat{S}_t) \tag{3}$$

The smallest value that $\hat{Z}_t$ can have would be:

$$\hat{Z}_{t\,min} = -\ln\left[\frac{\hat{N}_t - \hat{H}_t}{\hat{N}_t}\right] \tag{4}$$

Annual sampling mortality of fully recruited fish (if any) was added to the estimated harvest for the respective populations. Estimates of annual recreational harvest between 1977-1992 are available from the statewide harvest survey (SHS, Mills 1987-1993). Hallberg and Bingham (1992) estimated that 85% of the northern pike harvested in George Lake were $\geq$500 mm FL. Therefore, the harvest reported in the SHS was multiplied by 0.85 to obtain an estimate of the harvest of fully recruited northern pike (H*). The greater of the two values (Z_t or $Z_{t\,min}$) was used in Baranov's catch equation to apportion total mortality (Z) between fishing (F) and natural (M) mortalities. Baranov's catch equation (Ricker 1975) was re-organized and solved for F:

$$\hat{F} = \frac{\hat{Z}}{\hat{A}} * \frac{\hat{H}^*}{\hat{N}}; \tag{5}$$

where:

$\hat{H}^*$ = the corrected estimated harvest from the statewide harvest survey;
$\hat{Z}$ = the instantaneous total mortality rate;
= $-\ln \hat{S}$;
A = annual mortality rate;
= $1 - e^{-z}$.

Surplus Production Models

Two methods were used to analyze the stock-recruitment relationship and estimate the maximum surplus production: the logistic surplus production model and Ricker's spawner-recruit model (Ricker 1975). Potential surplus production resulting from fry production in year *t* becomes realized surplus production (i.e., abundance at recruitment) in year *t+age at maturity*. To directly calculate estimates of surplus production with either model, data from mark-recapture experiments must include at least two estimates of abundance for fully recruited (mature) northern pike, followed by estimates of abundance for their respective progeny at maturity. Therefore, annual studies would have to have been conducted for 7 years in George, Volkmar, and Harding lakes, and 8 years in T Lake to directly estimate MSY. Indirect (*ad hoc*) methods must be used for populations where the database is insufficient to directly estimate MSY.

Logistic Surplus Production Model, Indirect Method:

Ad hoc methods were necessary to estimate the parameters for a logistic surplus production model in George and Harding lakes because population data was available for only 6 and 4 years, respectively. Gulland (1983) has shown that for many fish populations an empirical, conservative relationship exists between the instantaneous rate of natural mortality (M), carrying capacity of the environment (K), and MSY:

$$\begin{aligned} MSY &= 0.3\ MK \\ &= 0.3(-\ln S - F)K \end{aligned} \qquad (6)$$

MSY can also be expressed as a function of the intrinsic rate of population increase (r), and K (Ricker 1975, Gulland 1983):

$$MSY = \frac{rK}{4} \qquad (7)$$

Equations (6) and (7) were combined and solved for the intrinsic rate of population increase:

$$r = 4(0.3)(-\ln S - F) \qquad (8)$$

Surviving recruitment (R) in any year is a function of surplus production (SP) and of the production needed to compensate for natural mortality during the previous time interval:

$$R = SP + (1 - e^{-M})N \qquad (9)$$

If surplus production is defined as a linear function of r and K, the above equation becomes:

$$R = rN\left[1 - \frac{N}{K}\right] + (1 - e^{-M})N \qquad (10)$$

With this model, maximum surplus production occurs when the abundance (or biomass) is equal to 50% the carrying capacity (K), and is equal to one-quarter of K multiplied by a value of r pertaining to low levels of population abundance. Therefore, if the abundance is at the level which produces maximum sustainable yield (N_{MSY}), subsequent recruitment will also be at a maximum (R_{MAX}). The formulation then becomes:

$$R_{MAX} = rN_{MSY}\left[\frac{\frac{K}{2}}{K}\right] + (1 - e^{-M})N_{MSY} \qquad (11)$$

$$= N_{MSY}(\tfrac{3}{2}r - e^{-M})$$

With estimates for r, M, and R_{MAX} (assumed to be the largest observed recruitment), and with the knowledge that $N_{MSY} = K/2$, the above equations can be solved for N_{MSY}, K, and MSY.

A Monte Carlo simulation was done to approximate the variance around the estimated MSY parameter. It was assumed that fishing mortality followed a normal distribution and had a uniform (non-seasonal) influence over time. The following protocol was used in the simulation:

1. three random numbers were generated from a standard normal distribution ($\mu = 0$, $\sigma = 1$) for the estimates of Z, F, and R_{MAX};

2. the random numbers were then transformed with the appropriate mean and standard deviation, the standard deviation was approximated for Z and F as the observed range divided by 4;

3. M was calculated as Z - F;

4. S was calculated as e^{-Z};

5. R, N_{MSY}, MSY, and K were then calculated;

6. steps 1 through 5 were repeated for 5,000 iterations; and,

7. the mean (standard arithmetic mean) and variance of the 5,000 estimates was calculated.

Logistic Surplus Production Model, Direct Method:

The database for Volkmar and T lakes allow for at least two entries into a brood table. With a minimum of two entries, estimates of the intrinsic rate of increase and the carrying capacity for the population can be directly calculated. With two estimates of spawner abundance and the resultant recruitment, equation (11) was solved simultaneously for K and r. The average rate of instantaneous mortality ($\overline{M}$) was used in the calculations for M.

Ricker's Model:

Ricker's stock-recruitment relationship was developed under the assumption that density-dependent mortality is affecting the eggs and juveniles in the population. In the Ricker model there is usually declining recruitment at higher stock sizes. The model follows four basic properties:

1. The stock-recruitment curve should pass through the origin.

2. The curve should not fall to the abscissa at higher levels of stock, so that there is no point at which reproduction is completely eliminated at high densities.

3. The rate of recruitment should decrease continuously with increase in parental stock.

4. Recruitment must be high enough over some range of stock sizes to more than replace annual due to natural mortality losses.

The stock recruitment model proposed by Ricker is:

$$R = \alpha N e^{-\beta N} \qquad (12)$$

where:

- R = the number of recruits;
- N = abundance of spawning fish;
- α = a dimensionless parameter often considered stock-specific and associated with density-independent factors; and,
- β = a parameter with dimensions of 1/N, usually associated with density dependent factors.

The equation was then solved for α and β using non-linear regression (PROC NLIN in the software SAS®).

Maximum level of recruitment is obtained when the abundance of spawners is:

$$N_{Rmax} = \frac{1}{\beta} \qquad (13)$$

R_{MAX} was calculated by substituting (16) into (15):

$$R = \frac{\alpha}{\beta e} \qquad (14)$$

The replacement line was calculated as:

$$R = \hat{N}(1 - \hat{S}) \qquad (15)$$

The maximum sustainable yield was calculated as the greatest difference between the replacement line and reproduction curve. Volkmar Lake was the only population with a database that had sufficient estimates of both spawning stock and recruitment to use this method.

RESULTS

George Lake

The estimated maximum sustainable yield for George Lake was 2,574 northern pike ≥500 mm FL (Table 1, Figure 2). The Jolly-Seber method (Seber 1982) was used to re-estimate abundance ($\hat{N}$), annual survival rates ($\hat{S}$), and surviving recruitment of fully recruited northern pike (Figure 3, Appendix B). Because of the large error associated with the estimates of recruitment from the Jolly-Seber method ($SE(\hat{B})$), the estimated abundance of age 5 northern pike (estimated proportion of age 5 northern pike, P_{age5}, multiplied by the estimated population abundance of northern pike over 499 mm) was used in the calculation of MSY. Substituting the average annual survival rate

Table 1. Summary of estimates from the logistic surplus production model for northern pike in four lakes.

Lake	Area (ha)	Intrinsic Rate of Increase (r)	Carrying Capacity (K)	Abundance at MSY (N_{MSY})	Maximum Sustainable Yield (MSY)	Density at N_{MSY} (D_{NMSY})	Yield per ha at MSY (Y_{MSY})
George	1,823	0.42	24,400	12,200	2,574	6.7	1.4
Volkmar							
Indirect	273	0.45	5,942	2,971	675	10.9	2.5
Direct	273	0.43	2,774	1,387	298	5.1	1.1
T	158	0.48	494	247	59	1.6	0.4
Harding	1,000	0.23	6,765	3,383	390	3.4	0.4

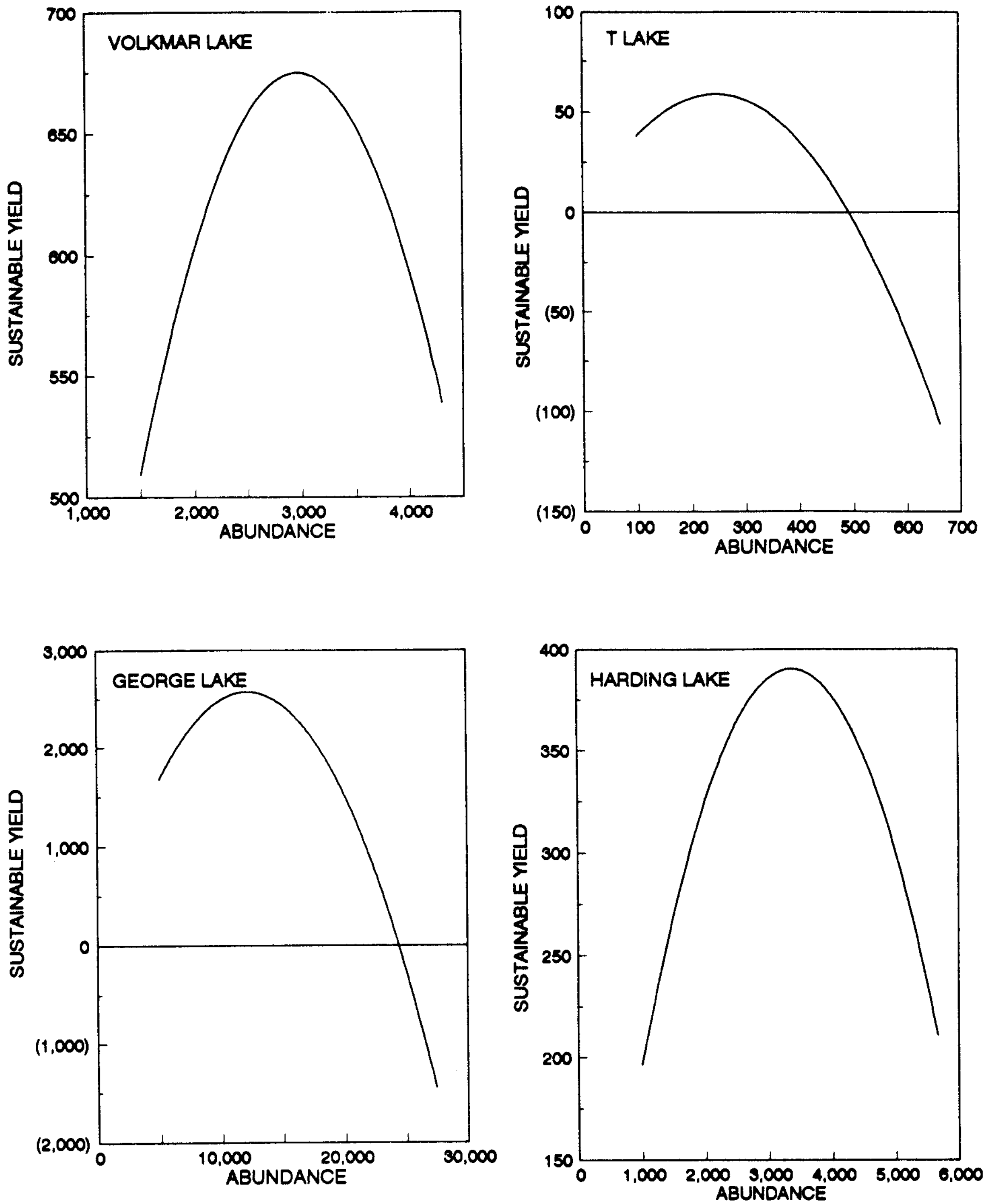

Figure 2. Estimates of the northern pike sustainable yield for various levels of spawner abundance in four study lakes.

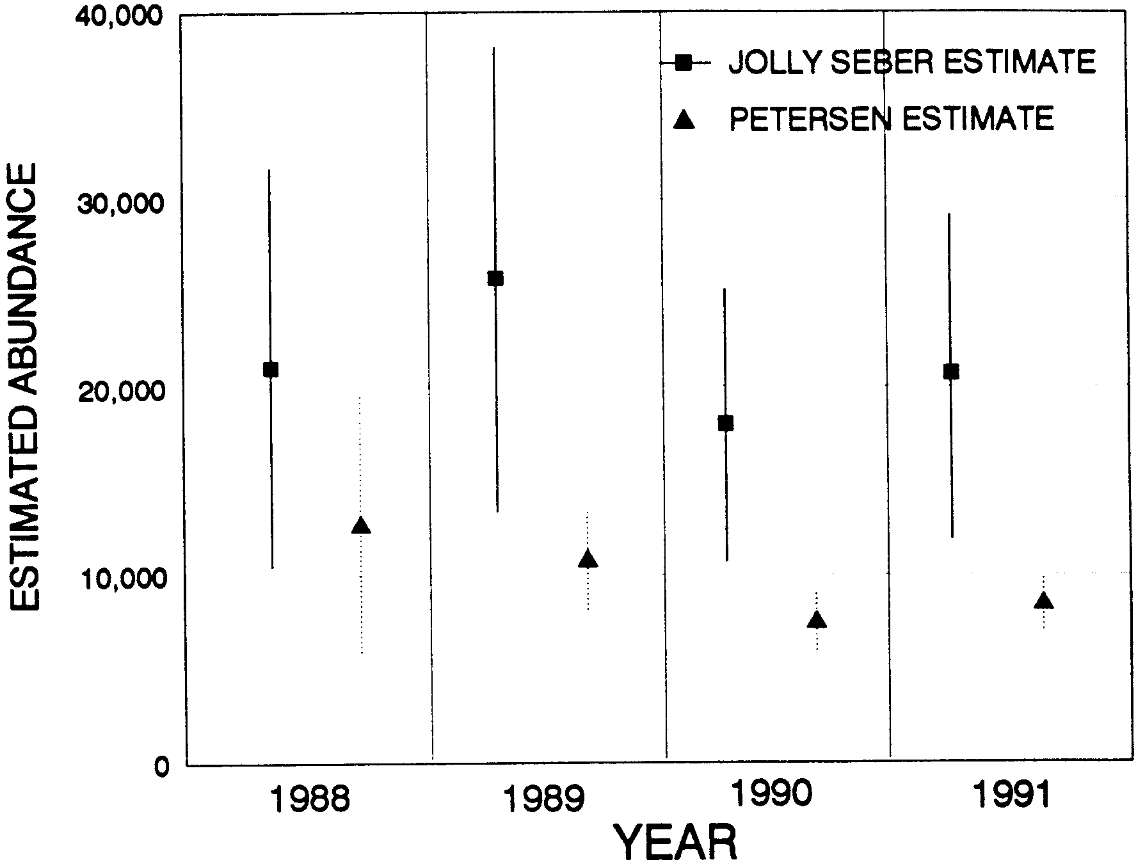

Figure 3. Comparison between Petersen and Jolly-Seber abundance estimators for northern pike in George Lake.

($\hat{S}$ = 0.663, Table 2) and the average instantaneous rate of fishing mortality ($\hat{F}$ = 0.061) into equation (8), the intrinsic rate of increase was estimated to be 0.42 (Table 1). The largest estimated abundance of age 5 fish observed (6,185), was used as an estimate of R_{MAX}. Substituting the value of R_{MAX} into equation (11) resulted in an estimated N_{MSY} of 12,200 northern pike $\geq$500 mm FL. The carrying capacity (N_{MSY}*2) was then 24,400 northern pike $\geq$500 mm FL. Substituting these estimates into equation (7) resulted in an estimated maximum sustainable yield of 2,574 northern pike $\geq$500 mm FL (Table 1, Figure 2). The Monte Carlo simulation produced a mean MSY of 2,575 with a standard error of 760 fully recruited northern pike (Figure 4).

In 1991, the estimated recruitment was 4,310 northern pike (Table 2), and the estimated harvest was only 1,074 fully recruited fish. The 1991 estimated abundance of 20,524 fully recruited fish should produce a sustainable yield of approximately 1,376 fully recruited fish in 1997 (Figure 5).

Volkmar Lake

The estimated average annual survival was 0.60 in Volkmar Lake (Table 3). The average instantaneous rate of fishing mortality was estimated to be 0.13. Substituting these values into equation (8), the intrinsic rate of increase was estimated to be 0.45 for the *ad hoc* logistic surplus production method (Table 1). Substituting the value of R_{MAX} (1,611) into equation (11) resulted in an estimated N_{MSY} of 2,971 northern pike age 5 and older. The carrying capacity would then be 5,942 northern pike age 5 and older. Substituting these estimates in equation (7) resulted in an estimate of maximum sustainable yield of 675 northern pike age 5 and older (Figures 3 and 6) according to this method. The mean MSY from the Monte Carlo simulation was 677 (SE = 126) fully recruited northern pike (Figure 4).

At lower levels of spawner abundance the logistic surplus production model predicted recruitment below what was observed (Figure 6). Both the predicted and observed recruitment were at or above the estimated harvest for the years 1990-1992. The 1988 estimated abundance of 2,095 spawners (Table 3) should have produced a sustainable yield of approximately 616 fully recruited fish in 1993 (Figures 3 and 5). The estimated recruitment in 1993 (886, SE = 149) is not significantly different from the predicted value ($Z = 1.8$, $P = 0.08$). The present level of abundance of 2,893 fish is expected to produce a sustainable yield of 674 fully recruited northern pike in 1998.

There were four pairs of spawner abundance and resultant recruitment estimates for the years 1985 and 1990, 1986 and 1991, 1987 and 1992, and 1988 and 1993. Six estimates of the intrinsic rate of increase and carrying capacity were calculated (Table 4) to directly estimate logistic surplus production. The estimates of the intrinsic rate of increase ranged from 0.23 to 0.76 with a mean of 0.43. Estimates of the carrying capacity ranged from 2,343 to 3,294 with a mean of 2,774 northern pike.

Ricker's model of surplus production ($\alpha = 1.49$, $\beta = -0.0006$) predicted the MSY to be 430 fully recruited fish (Figure 6). A spawner abundance of 901 northern pike is needed to produce that level of recruitment. The replacement line intersected the reproduction curve when the spawner abundance was 2,230

Table 2. Summary of Jolly-Seber estimates for fully recruited northern pike from George Lake.

Year	$\hat{N}$ (SE)	$\hat{S}$ (SE)	$\hat{P}_{age5}$ (SE)	$\hat{R}$ (SE)	$\hat{F}$	$\hat{M}$	$\hat{H}$*
1987		0.933(0.197)	0.23 (0.04)				1,895
1988	21,096 (5,415)	0.461 (0.102)	0.16 (0.03)	3,375 (1,074)	0.090	0.321	1,561
1989	25,771 (6,306)	0.309 (0.534)	0.24 (0.04)	6,185 (1,804)	0.036	0.376	750
1990	17,899 (3,699)	0.948 (0.191)	0.28 (0.03)	5,012 (1,140)	0.055	0.357	803
1991	20,524 (4,394)		0.21 (0.02)	4,310 (1,008)	0.064	0.348	1,074
MEAN	21,323	0.663		4,720	0.061	0.351	1,217

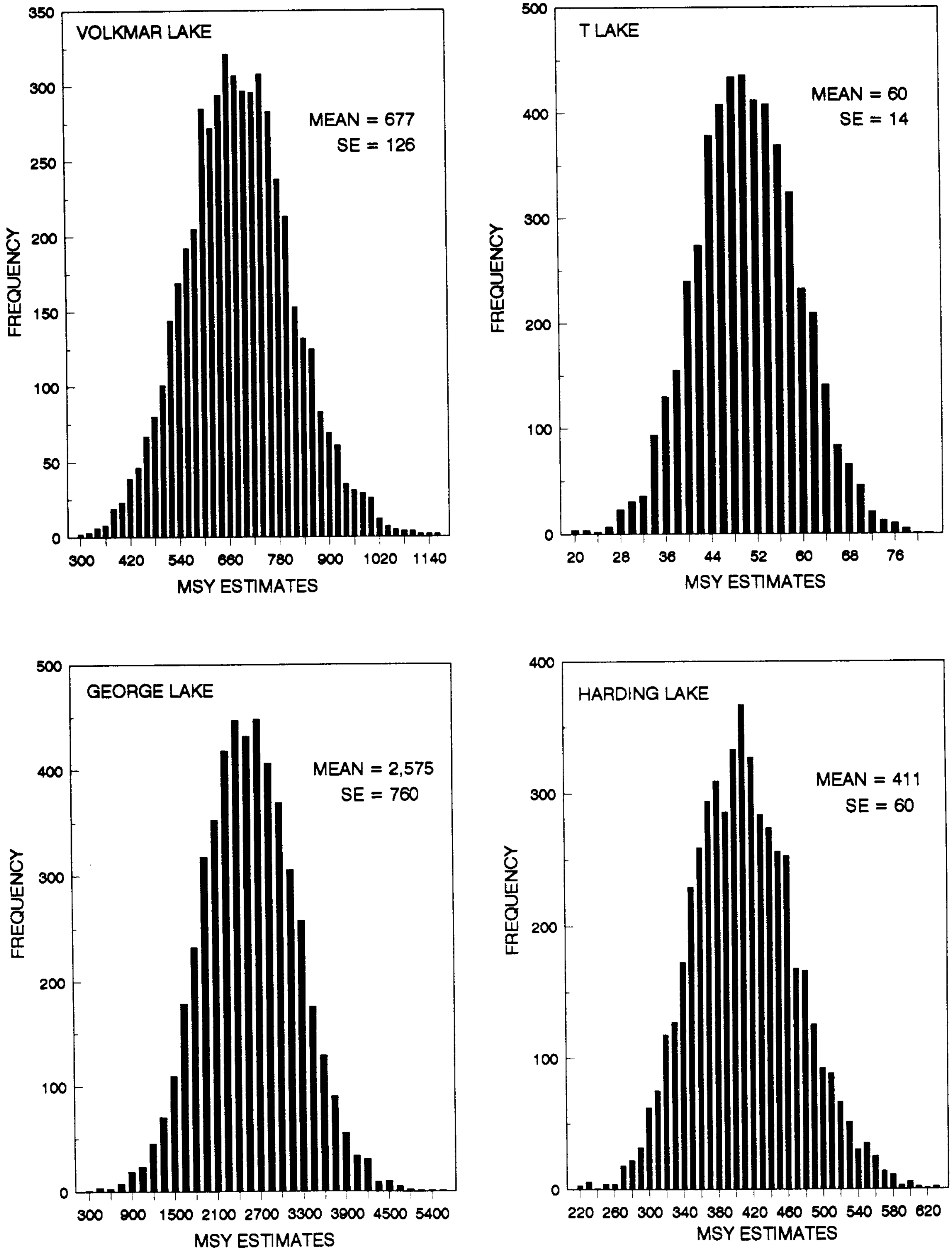

Figure 4. Frequency histograms of 5,000 Monte Carlo simulation estimates of maximum sustainable yield for northern pike in four lakes.

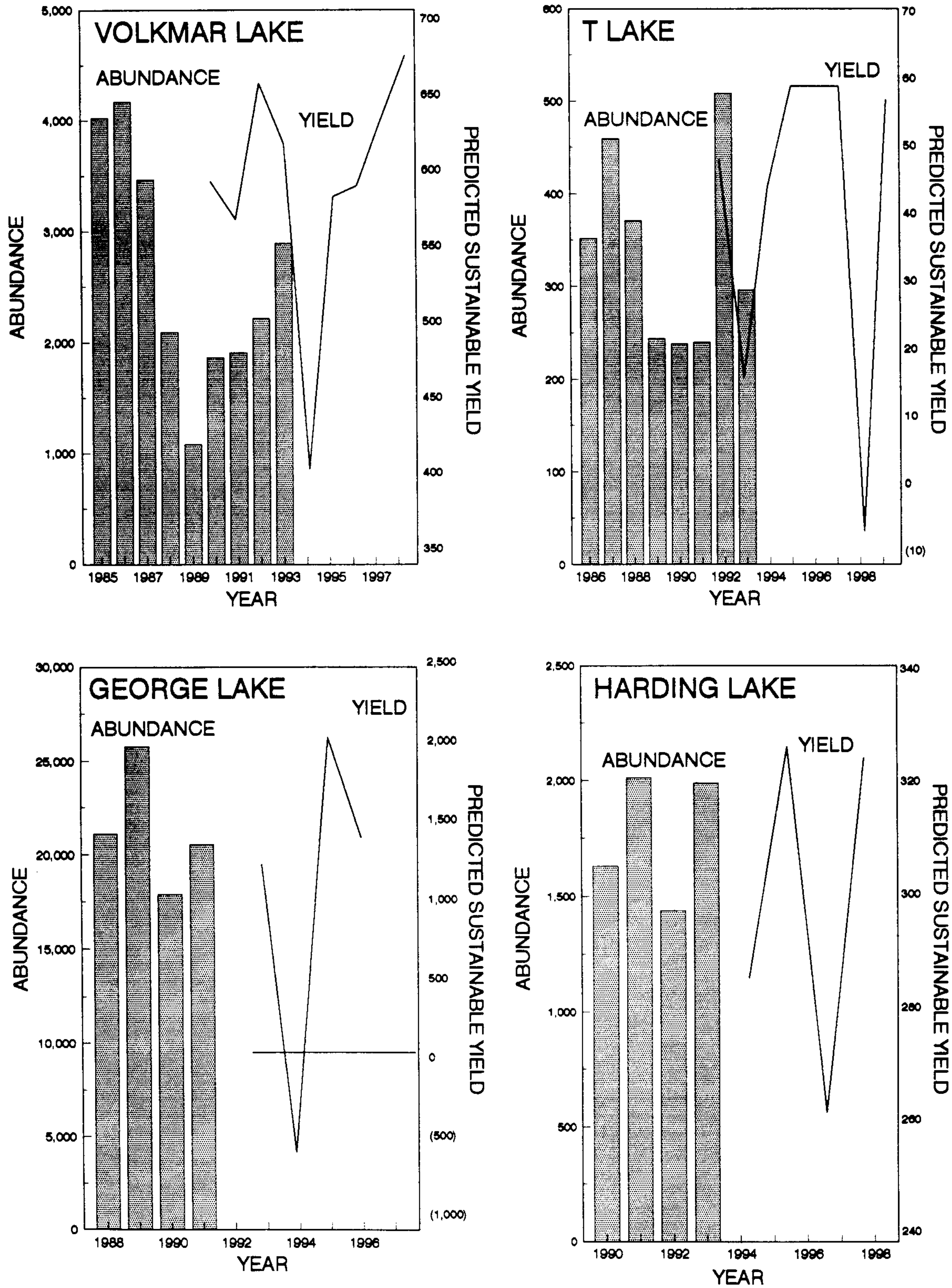

Figure 5. Abundance estimates of fully recruited northern pike and expected resultant yield for four study lakes.

Table 3. Summary of estimates from the logistic surplus production model for fully recruited northern pike from Volkmar Lake.

Year	$\hat{N}$ (SE)	$\hat{R}$ (SE)	$\hat{S}$ (SE)	$\hat{H}^*$	$\hat{Z}$	$\hat{Z}_{min}$	$\hat{Z}_{used}$	$\hat{F}$	$\hat{M}$
1985	4,020 (250)	1,238 (137)	0.72 (0.16)	584	0.32	0.11	0.32	0.17	0.15
1986	4,168 (531)	1,262 (316)	0.44 (0.12)	673	0.81	0.14	0.81	0.24	0.57
1987	3,465 (333)	1,611 (284)	0.37 (0.06)	190	0.99	0.06	0.99	0.09	0.90
1988	2,095 (126)	804 (0)	0.39 (0.06)	217	0.94	0.11	0.94	0.16	0.78
1989	1,081 (102)	263 (52)	1.00 (0.26)	153	0.01	0.15	0.15	0.14	0.01
1990	1,866 (218)	599 (130)	0.77 (0.13)	71	0.27	0.04	0.27	0.04	0.22
1991	1,909 (159)	479 (81)	----	480	----	----	----	----	----
1992	2,216 (334)	708[a] ----	0.96 (0.19)	196	0.04	0.09	0.09	0.09	0.00
1993	2,893 (238)	886 (149)	----	----	----	----	----	----	----
MEAN	2,635	893	0.60[b]	321			0.51	0.13	0.38

[a] Estimate of recruitment in 1992 were obtained from mean length at age analysis because scales were not taken from all fish.

[b] Average S = e^{-Z}.

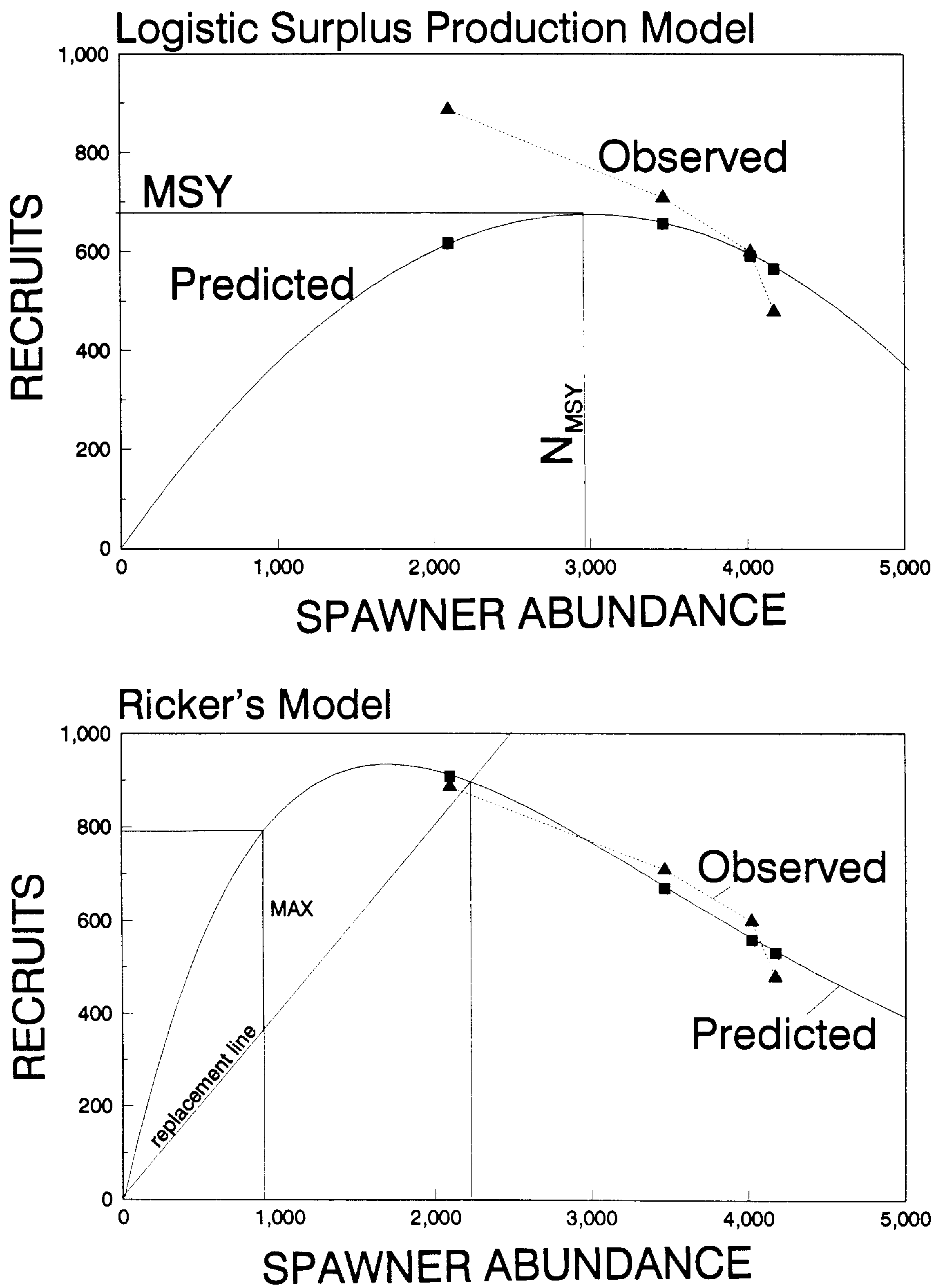

Figure 6. Estimates of maximum sustainable yield from two surplus production models for northern pike populations in Volkmar Lake.

Table 4. Estimates of the intrinsic rate of increase and carrying capacity directly calculated from the logistic surplus production model for northern pike in Volkmar Lake.

Spawning Year	Spawner Abundance	Recruitment Year	Recruit Abundance	Intrinsic Rate of Increase	Carrying Capacity
1985	4,020	1990	599	0.76	3,294
1986	4,168	1991	479		
1985	4,020	1990	599	0.23	2,343
1987	3,465	1992	708		
1985	4,020	1990	599	0.40	2,845
1988	2,095	1993	886		
1986	4,168	1991	479	0.33	2,585
1987	3,465	1992	708		
1986	4,168	1991	479	0.42	2,814
1988	2,095	1993	886		
1987	3,465	1992	708	0.44	2,764
1988	2,095	1993	886		
			Average	0.43	2,774

northern pike. The maximum recruitment was 930 northern pike produced by an abundance of 1,700 spawners.

T Lake

The estimated average survival was 0.59 in T Lake (Table 5). The average instantaneous rate of fishing mortality was estimated to be 0.14. The estimated intrinsic rate of increase was 0.48 (Table 1). Using a maximum recruitment of 140 northern pike produced an estimated N_{MSY} of 247 fish age 6 and older. The carrying capacity was estimated to be 494 northern pike age 6 and older. The estimated maximum sustainable yield was then 59 northern pike age 6 and older (Figure 3). A mean MSY of 60 fully recruited northern pike SE = 14) was produced by the Monte Carlo simulation (Figure 4).

According to the logistic surplus production model, the estimated 459 spawners in 1987 should have produced 16 recruits in 1993 (Figures 3 and 7). Sampling in 1993 estimated recruitment to be 140 (SE = 31) northern pike. The present level of abundance of 296 spawners is expected to produce 57 fully recruited northern pike in 1999.

Attempts to directly calculate surplus production, based upon the number of spawners in 1986 and 1987 and the number of recruits in 1992 and 1993, resulted in an impossible negative estimate of r.

Harding Lake

The estimated average survival was 0.46 in Harding Lake (Table 6). The average instantaneous rate of fishing mortality was estimated to be 0.58.

Substituting these values into equation (8), the intrinsic rate of increase was estimated to be 0.23 (Table 1). Using an R_{MAX} of 648 resulted in an estimated N_{MSY} of 3,383 and a carrying capacity of 6,765 northern pike age 5 and older (Table 1, Figure 2). The MSY was then estimated to be 390 northern pike age 5 and older. The mean MSY from the Monte Carlo simulation was 411 (SE = 60) fully recruited northern pike (Figure 4).

The present level of abundance of 1,989 spawners is expected to produce a sustainable yield of 324 fully recruited northern pike in 1998 (Figure 5).

DISCUSSION

Unless mortality (natural or fishing) increases, the abundance of northern pike in George Lake will likely remain above the optimum level and yields below maximum potential. The 1991 estimated abundance of fully recruited northern pike in George Lake was 20,524 (SE = 4,394, Table 1). This point estimate is greater than the optimum spawner abundance predicted by the logistic surplus production model (12,200) and is approaching the carrying capacity (24,400). The predicted sustainable yield for 1993 and 1994 (1,205 and 608 northern pike, respectively) is below the average sport harvest for George Lake ($\hat{\bar{H}}$ = 1,217). However, the 1992 estimated harvest of northern pike in George Lake was only 449.

Table 5. Summary of estimates from the logistic surplus production model for fully recruited northern pike from T Lake.

Year	$\hat{N}$ (SE)	$\hat{R}$ (SE)	$\hat{S}$ (SE)	$\hat{H}$	$\hat{Z}$	$\hat{Z}_{min}$	$\hat{Z}_{used}$	$\hat{F}$	$\hat{M}$
1986	352 (48)	73 (22)	0.95 (0.18)	108	0.05	0.00	0.37	0.31	0.05
1987	459 (41)	125 (22)	0.58 (0.09)	21	0.55	0.00	0.55	0.06	0.49
1988	371 (29)	107 (25)	0.56 (0.09)	36	0.58	0.90	0.58	0.13	0.45
1989	244 (29)	36 (20)	0.72 (0.17)	5	0.33	0.00	0.33	0.02	0.30
1990	238 (33)	62 (16)	0.82 (0.16)	0	0.19	0.00	0.19	0.00	0.19
1991	240 (26)	44 (10)	----	0	----	----	----	----	----
1992	508 (52)	91[a] ---	0.31 (0.11)	0	1.18	0.00	1.18	0.00	1.18
1993	296 (41)	140 (31)	----	-	----	----	----	----	----
MEAN	339	84	0.59[b]	29			0.53	0.14	0.40

[a] Estimate of recruitment in 1992 were obtained from mean length at age analysis because scales were not taken from all fish.

[b] Average $S = e^{-Z}$.

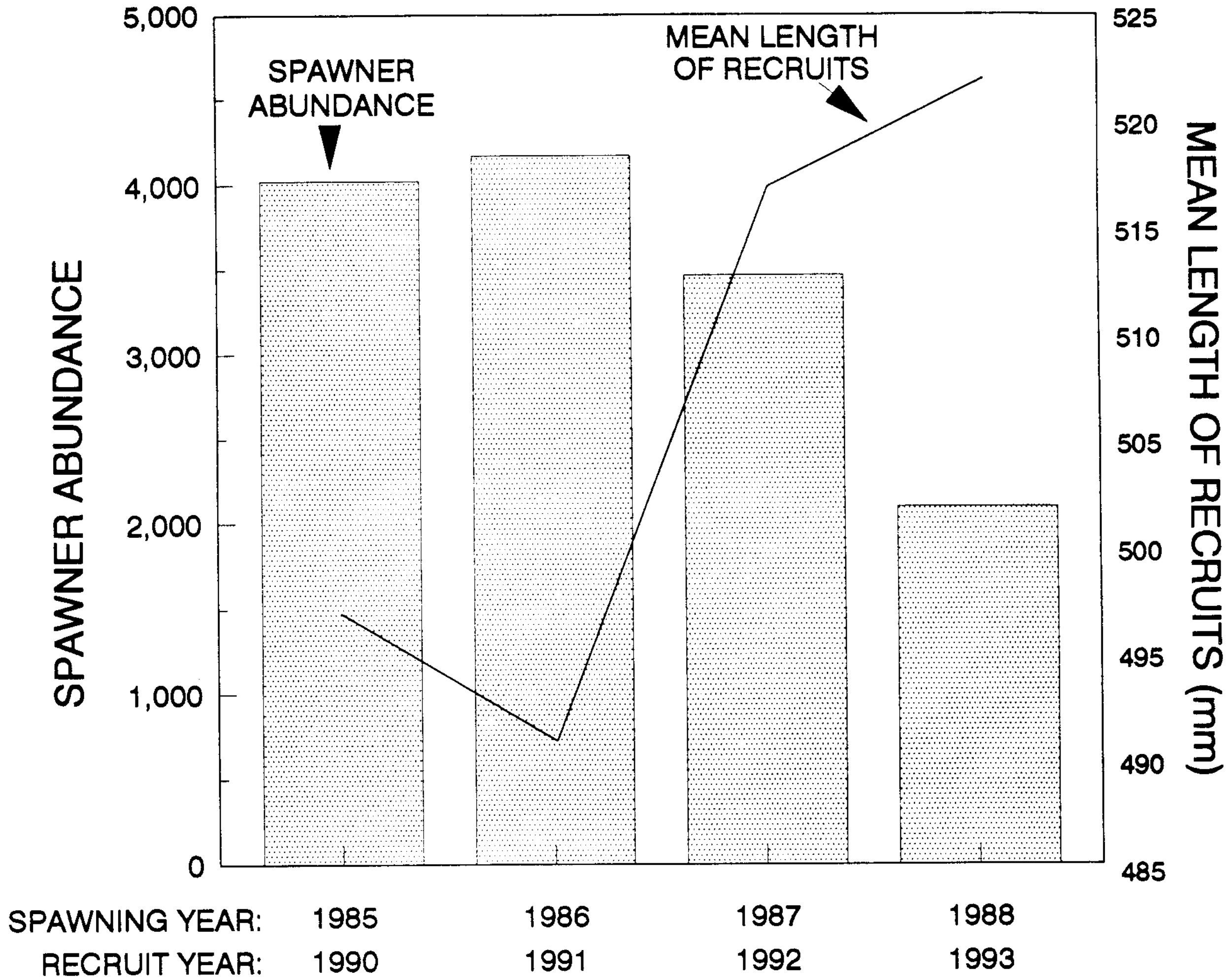

Figure 7. Estimates of abundance of fully recruited northern pike and the mean length of the resultant recruits in Volkmar Lake.

Table 6. Summary of estimates from the logistic surplus production model for fully recruited northern pike from Harding Lake.

Year	$\hat{N}$ (SE)	$\hat{R}$ (SE)	$\hat{S}$ (SE)	$\hat{H}$	$\hat{Z}$	$\hat{Z}_{min}$	$\hat{Z}_{used}$	$\hat{F}$	$\hat{M}$
1990	1,630 (155)	657 (125)	1.00 (0.20)	502	-0.02	0.37	0.37	0.30	0.06
1991	2,011 (245)	343 (131)	0.41 (0.09)	1,605	0.89	1.60	1.60	1.20	0.40
1992	1,438 (128)	609 (97)	0.70 (0.15)	290	0.36	0.23	0.36	0.24	0.12
1993	1,989 (155)	982 (126)	----	---	----	----	----	----	----
MEAN	1,767	648	0.46[a]	799			0.77	0.58	0.19

[a] Average $S = e^{-Z}$.

According to the indirect model, Volkmar Lake is close to its' maximum production. The Volkmar Lake estimated abundance in 1993 (2,893 SE = 238) is very close to the N_{MSY} (2,971) value predicted by the indirect LSP model. Based on low spawner abundance in 1989, the model predicts a decline in the sustainable yield in 1994 (SY = 402). This sustainable yield is close to recent harvest levels, and there should not be a problem with this fishery providing harvest follows recent trends.

Based on Ricker's model in Volkmar Lake, maximum surplus production occurs when spawner abundance is 900 fish. This is significantly less than the most recent (May 1993) level of abundance. If the Ricker model more adequately describes the spawner-recruit relationship than the LSP model, then present levels of abundance are well below replacement level and cannot be sustained. Ricker's model predicts close to the maximum recruitment in 1994 based on the low spawner abundance in 1989 (Figure 6).

The non-linear regression model which was used to fit the Ricker spawner recruit curve fits the data well but the predicted curve is biologically impossible. The maximum recruitment estimated by the model would need to be much greater to account for the fluctuations in spawner abundance that have been seen. If a population starts at equilibrium and is pulse fished, the abundance will begin to cycle (Ricker 1975). The amplitude of this cycle is the difference between the maximum number of recruits and the number of recruits at equilibrium. In the case of Volkmar Lake, the amplitude of the predicted cycle is 40 northern pike (930-890) which could not describe the fluctuations of abundance and magnitude of recruitment that have occurred in the northern pike population in Volkmar Lake. Because little data has been collected for spawner abundance's below equilibrium, the number of maximum recruits predicted could very well be too low. If the maximum number of recruits is potentially higher, the Ricker curve would be more peaked and the associated estimation of MSY would also be higher.

The population of northern pike in T lake appears to have the potential for a near-term increase. This is based upon the 1993 level of abundance (close to N_{MSY}), recruitment in both 1992 and 1993 that exceeded expectations (Figure 6), and a prediction of continuing good surplus production for the years 1994-1997. Based upon observed recruitment, our estimates of N_{MSY}, MSY, and K are likely conservative. This is probably not due to our estimates of abundance and composition, which are reasonable and have met strict objective criteria. Rather, due to insufficient harvest data, we have probably underestimated fishing mortality (F, Table 5), and if so, overestimated natural mortality (M), and underestimated r, K, and MSY.

The population of mature northern pike in Harding Lake appear to be recovering from a period of overexploitation. Estimates of abundance and composition indicate a recent trend of improved recruitment and survival, and decreased harvest (Table 5, Figure 5). The estimated abundance in 1993 for northern pike in Harding Lake (1,989, SE = 155) was about half the estimated value of N_{MSY} (3,383) for that population. Sustainable yields are expected to vary between 260 and 320 northern pike from 1994 to 1998. For the period 1983 to 1992, the average harvest of fully recruited northern pike from Harding Lake was 799 fish, well above the sustainable levels. There were an estimated 290 recruited northern pike harvested in 1992. If present levels of harvest increase, Harding Lake will not reach its' maximum production potential.

The estimates of the intrinsic rate of increase (r), which is likely a species specific parameter often modified by environmental factors and population density (Ricklefs 1979), is very similar between Volkmar, George, and T lakes. This is expected, since we derived r from estimates of natural mortality (equation 8; Tables 1, 3, and 5) which varied little among these populations. Estimates of natural mortality, and hence r, were therefore lower in Harding lake. This is due to fishing mortality likely replacing a significant portion of natural mortality in Harding Lake (Table 6), which is a result of the recent high levels of recreational harvest. Estimates of average annual survival were approximately 60% for George, Volkmar, and T lakes, and only 46% in Harding Lake. Density at estimated N_{MSY} (fish/ha, D_{NMSY}), was highest in Volkmar Lake (10.8), followed by populations in George (6.7), Harding (3.4), and T (1.6) lakes. Potential maximum surplus yield (MSY/ha, Y_{MSY}) was again highest for Volkmar Lake (2.5) followed by George, T and Harding lakes (1.4, 0.4, and 0.4 respectively).

The estimates in this study agree with those of other studies. Bregazzi and Kennedy (1980) estimated the survival of all northern pike over ≥500 mm FL in Slapton Ley (England) to be 0.59 and estimated the density to be 10.1 (range 5.3 to 13.9) northern pike per ha. Kempinger and Carline (1978) estimated the average density to be 6.9 northern pike ≥560 mm FL per ha in Escanaba Lake (Wisconsin).

The Ricker model appears to better describe the spawner-recruit relationship of northern pike in Volkmar Lake than the logistic surplus production model. The LSP model is symmetrical about N_{MSY}, while the Ricker curve is asymmetrical (skewed right), with much steeper ascending and shallower descending limbs and with a lower estimate of N_{MSY}. While the LSP is density dependent, it appears as if the spawner-recruit relationship for northern pike in Volkmar Lake is more sensitive to density than the LSP allows. Density-dependence has been documented for northern pike by Kempinger and Carline (1978), who noted increased total (and natural) mortality, decreased rates of growth and condition, and lower yield under conditions of increasing density during experimental management of northern pike in Escanaba Lake (Wisconsin). Similarly, factors such as cannibalism among northern pike, and effects of the environment, have been implicated as mechanisms in determining survival at high levels of abundance of cohorts during their first year of life (Kipling 1983, Kipling and Frost 1970, and Le Cren 1987). The northern pike described were investigated during a long-term study (1940-1985) in Lake Windermere (England). In response to an increase in commercial exploitation, the population experienced a rapid decline in mean age of the stock, increased survival and recruitment, but no significant response in adult growth was observed. This was attributed to a measurable decrease of density-dependent cannibalism, and optimal environmental conditions. However, in our study of Volkmar Lake, the number of spawners in year t was negatively correlated with the average length of recruits in year $t+5$ ($r = -0.93$, $P = 0.06$, Figure 8), indicating increases in growth of fish due, in part, to lower levels of parent abundance.

Kipling and Frost (1970) and Kipling (1983, 1984) postulated that growth in the first year of life is critical in determining survival, i.e., faster growing, larger (>200 mm FL) northern pike of age 1 are more likely to avoid predation by cohorts and older fish. The authors felt optimum water

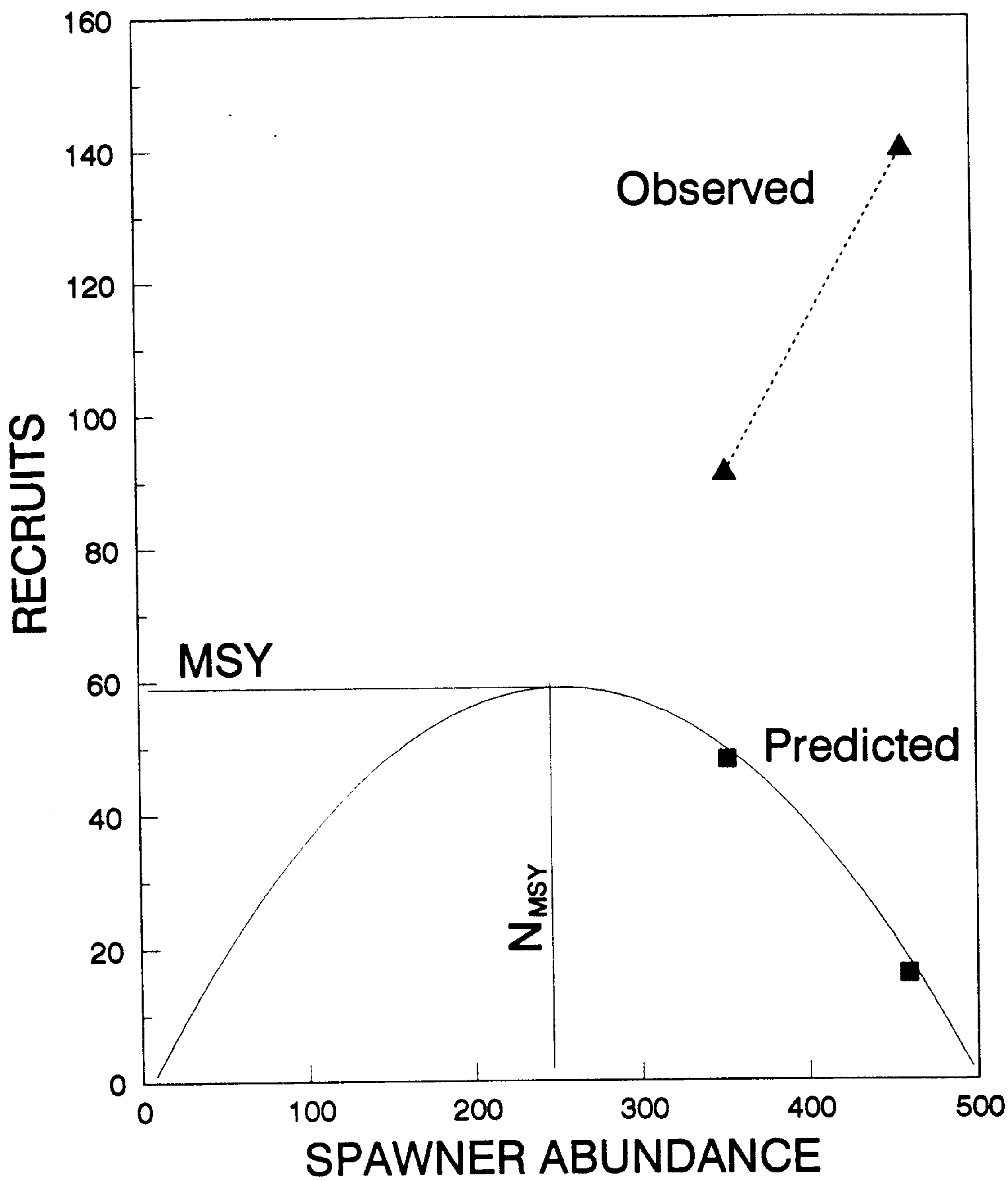

Figure 8. Logistic surplus production model predicted number of recruits for various levels of spawner abundance in T Lake.

temperature, acting by both influencing the rate of growth of northern pike and determining the length of the growing season (and therefore, in combination, the ultimate length at age 1), was the mechanism by which the environment affects rates of survival and therefore abundance at recruitment. The effects of variations in environmental temperature were less pronounced during pre-exploitation conditions in Lake Windermere, when the population consisted of a large number of relatively slow-growing year classes. The diverse composition of older cohorts was believed to have dampened the effects of potentially variable recruitment on overall population abundance, through both direct predation and increased rates of cannibalism both directly and as a result of surplus production of fry. Le Cren (1987) speculated that the rates of growth and magnitude of recruitment are fixed at a particular stage of life and may change only with successive year classes, emphasizing the value of cohort analysis.

The effects of environmental conditions on recruitment and production have been widely implicated in studies additional to those cited. Downing and Plante (1993), in their summary analysis of 100 fish populations that included northern pike, suggest annual fish production is positively correlated with temperature, lake phosphorus concentration, chlorophyll a concentration, primary production, and with pH. Schlesinger and Regier (1983) found significant correlation between sustained yield and long-term mean annual air temperature, with 1.5°C being optimum for the 16 populations of northern pike represented. Christie and Regier (1988) found that sustainable yield for 15 populations of northern pike was better correlated with measures of optimum Thermal Habitat Area (THA, 19-23°C), than with lake size or volume alone. This emphasizes the value of long-term studies in fishery research that collect data relative to both the fish population in question and their environment. We are currently obtaining environmental measurements (through a Graduate program) similar to the above for the lakes discussed.

The observed spawner-recruit data from T Lake, although limited, appears to reflect larger than expected recruitment (Figure 8). One reason for the disparity may be, as previously discussed, that the fishing mortality has likely been underestimated, the impact of which would have led to an underestimate of MSY and depression of the spawner-recruit relationship. Since T Lake is a remote fly-in lake obtaining better estimates of fishing mortality would be very expensive.

The logistic surplus production model presented (Gulland 1983, Ricker 1975, Tyler and Gallucci 1980), was chosen as a simplified representation of the relationship between observed spawner abundance and subsequent recruitment. The model assumes that the population has settled into relative equilibrium corresponding to abundance and fishing mortality, and that changes in environmental factors that affect rates of productivity are not permanently divergent. These assumptions may not be completely valid in some of the study lakes, especially Volkmar Lake where estimates of abundance have varied greatly. The Ricker model was also investigated. While the assumptions the Ricker model is based on are more reasonable, the predicted curve is impossible because the true relationship between spawners and recruits cannot be determined from only four data points. Sampling planned for spring 1994 should help clarify the spawner-recruit relationship. The parent year abundance (1989) of northern pike that will recruit at age 5 in 1994, was the lowest recorded (1,081) for the sampling period 1985-1993, and the resulting data point from 1994 will help define the shape of the curve that describes the relationship between the abundance of spawners and recruits. Additional data would also allow us to examine the population with a time series analysis.

ACKNOWLEDGMENTS

Numerous Regional staff have, since 1985, contributed their efforts to collect and interpret the data that supports this analysis. Former Regional Supervisor John H. Clark deserves credit for initial design, funding, and implementation of the northern pike research project. Biologists Bill Arvey, Alan Burkholder, Matt Evenson, Fronty Parker, Richard Peckham, Saree Timmons, and Cal Skaugstad are among many to be commended for their quality of data collection and analyses. The authors are especially grateful for the biometric counsel and guidance provided by Dave Bernard. We appreciate the critical review and technical support provided by Peggy Merritt. Thanks also go to Sara Case for proofing and printing of this report. The U. S. Fish and Wildlife Service provided partial funding for this study through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-9, Job No. R-3-4(c).

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APPENDIX A

Appendix A. Recreational fishing effort, harvest, and exploitation of northern pike in Volkmar, George, T, and Harding lakes, 1977-1992.

Lake/ Year	Angler Days[a]	Angler Days Per Ha	Harvest of Northern Pike[a]	Harvest Per Angler Day
Volkmar				
1981	458	1.7	648	1.4
1982	546	2.0	777	1.4
1983	270	1.0	430	1.6
1984	436	1.6	428	1.0
1985	711	2.6	503	0.7
1986	596	2.2	657	1.1
1987	472	1.7	224	0.5
1988	186	0.7	255	1.4
1989	466	1.7	180	0.4
1990	129	0.5	84	0.7
1991	1,052	3.9	565	0.5
1992	608	2.2	231	0.4
Mean	494	1.8	415	0.8
George				
1977	854	0.5	1,227	1.4
1978	1,271	0.7	1,392	1.1
1979	903	0.5	2,018	2.2
1980	1,057	0.6	1,395	1.3
1981	1,351	0.7	2,236	1.7
1982	989	0.5	1,635	1.7
1983	860	0.5	1,322	1.5
1984	557	0.3	1,700	3.1
1985	1,127	0.6	2,670	2.4
1986	1,957	1.1	3,076	1.6
1987	1,467	0.8	2,229	1.5
1988	964	0.5	1,837	1.9
1989	610	0.3	882	1.4
1990	1,540	0.8	945	0.6
1991	1,931	1.1	1,264	0.7
1992	1,067	0.6	529	0.3
Mean	1,157	0.6	1,647	1.4

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Appendix A. (Page 2 of 2).

Lake/ Year	Angler Days[a]	Angler Days Per Ha	Harvest of Northern Pike[a]	Harvest Per Angler Day
T				
1989	67	0.4	60	0.9
1992	---		---	
Harding				
1983	708	0.7	178	0.3
1984	1,707	1.7	766	0.5
1985	850	0.9	503	0.6
1986	2,064	2.1	673	0.3
1987	5,125	5.1	1,886	0.4
1988	3,256	3.2	2,092	0.6
1989	4,935	4.9	1,764	0.4
1990	3,895	3.9	591	0.2
1991	5,155	5.2	1,888	0.4
1992	5,068	5.1	341	0.1
Mean	3,276	3.3	1,068	0.3

[a] Data source: Mills 1979-1993, Mills pers. comm. 1983, 1985, 1992 (includes all size groups).

APPENDIX B

Appendix B. Jolly-Seber estimates of abundance, recruitment and survival for fully recruited northern pike in George Lake.

Data summarized in "B-Table" format (See Leslie, Chitty and Chitty 1953; Biometrika 40:137-169).

Time of last capture !	Time of recapture 1	2	3	4	5	6
1 !	0	42	22	7	5	5
2 !	0	0	19	7	14	1
3 !	0	0	0	30	16	12
4 !	0	0	0	0	75	34
5 !	0	0	0	0	0	40
6 !	0	0	0	0	0	0
Marked !	0	42	41	44	110	92
Unmarked!	1007	924	1207	1206	1189	936
Caught !	1007	966	1248	1250	1299	1028
Released!	1005	964	1248	1244	1294	1023

==== Survival rate estimates between sampling periods ====						Interval	Survival rate estimates per unit time (PHI**(1/T(i))			
Period	PHI	SE(PHI)	SE'(PHI)	95% Conf. interval	COV(PHI(i,i-1))	Length	PHI	SE(PHI)	95% Conf. interval	COV(PHI(i,i-1))
1	0.9334	0.1965	0.1963	0.5483 - 1.3185		1.0000	0.9334	0.1965	0.5483 - 1.3185	
2	0.4607	0.1023	0.1017	0.2601 - 0.6613	-.0095930784	1.0000	0.4607	0.1023	0.2601 - 0.6613	-0.0095930784
3	0.3085	0.0534	0.0524	0.2038 - 0.4131	-.0022260342	1.0000	0.3085	0.0534	0.2038 - 0.4131	-0.0022260342
4	0.9478	0.1915	0.1914	0.5726 - 1.3231	-.0022802224	1.0000	0.9478	0.1915	0.5726 - 1.3231	-0.0022802224
MEAN	0.6626	0.0614	0.0613	0.5422 - 0.7830			0.6626	0.0614	0.5422 - 0.7830	

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Appendix B. (Page 2 of 2).

Period	M	SE'(M)	95% Conf. interval		N	SE(N)	SE'(N)	95% Conf. interval	
2	938.07	197.29	551.38 -	1324.76	21095.70	5415.36	5415.24	10481.59 -	31709.81
3	866.61	167.77	537.79 -	1195.43	25771.34	6305.80	6305.36	13411.97 -	38130.70
4	643.86	96.22	455.27 -	832.45	17899.41	3698.53	3697.71	10650.29 -	25148.53
5	1752.44	341.83	1082.46 -	2422.42	20524.06	4393.77	4393.05	11912.27 -	29135.85
MEAN	1050.25	109.88	834.88 -	1265.61	21322.63	2526.03	2525.55	16371.60 -	26273.65

Period	p	SE(p)	95% Conf. interval	B	SE(B)	95% Conf. interval		COV(B(i),B(i-1))
2	0.0448	0.0115	0.0222 - 0.0674	16052.97	5211.22	5838.97 -	26266.97	
3	0.0473	0.0116	0.0245 - 0.0701	9949.31	3370.27	3343.59 -	16555.03	-7373791.34
4	0.0683	0.0142	0.0404 - 0.0962	3564.01	3870.22	-4021.61 -	11149.64	-8636720.99
5	0.0628	0.0135	0.0363 - 0.0892					
MEAN	0.0558	0.0002	0.0624 - 0.0631	9855.43	1544.64	6827.94 -	12882.92	